The Mamigasaki Alluvial Fan in the Yamagata Prefecture, as a Groundwater Reservoir

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Yoshiro TOMITA

I Introduction

The writer has made a preliminary report on the present subject in this Science Reports, series 7, 1959, under the title of "Structure of the Mamigasaki fan in the Yamagata Basin, Yamagata Prefecture, with regard to its facilities as a groundwater reservoir", in which he estimated a rechargeable water capacity of 40 million tons in the primary fan underlying the secondary superficial fan. Five years has passed since this publication. The writer may be under the obligation to make it clear whether this estimate was reasonable or not by this final report.

First of all, the writer must extend his sincere thanks to the members of the Municipal Water Supply Bureau of Yamagata City and the Municipal Planning Section of the city, also to the Professors of the Yamagata University, for their diversified works carried out concerning the groundwater of the Mamigasaki fan and the Yamagata basin.

II Condition of the water-supply in Yamagata City

Yamagata City is located in the eastern part of the Yamagata Basin and the Mamigasaki fan. The urbanized quarter of the city occupies the margin of the fan. The city has been established as a castle town in the 14th century and today, we can see, at the site of the castle some moats surrounding the stonewalls of the castle which was located at a spring zone at the margin of the fan. Yamagata City is a seat of the prefectural government of Yamagata since the end of the feudal age, and it has a population of 189,000 in the census of 1960.

Generally speaking, the groundwater in an alluvial fan is not distributed ubiquitously unlike the groundwater in a piedmont region or a region at the foot-slope of a volcano. Along the margin of a fan, groundwater is gushing to its surface forming a spring zone (Fig. 3). On the contrary, in the central part of a fan, the water-table is very low owing to the permeability of thickly accumulated fanglomerates, so that on the surface of this part of fan the surface water, the river water and the rain water easily permeate.

The source of city water in Yamagata City hitherto was mainly the water of

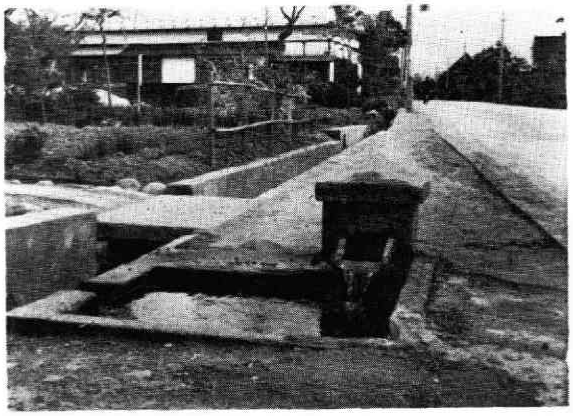

Photo. 1 Artesian well (depth of 50m) with a water pool for washing of vegetables near the lower terminal margin of the Mamigasaki fan by a street of Yamagata City. (By courtesy of Assoc. Prof. T. Kato of Yamagata Univ.)

the Mamigasaki river flowing along the northern margin of the Mamigasaki fan from the east to the west from its apex to urbanized area of the outskirt. Above this, the water for domestic use of the citizen living in the residence quarter to the east of the urbanized area has been supplied mainly by many shallow wells in each house. But there is increased demand of water in accordance with the increased population of the city. However, the water from the Mamigasaki river is not used exclusively for city water. The water must be shared in a considerable amount for irrigation to the paddy fields in the basin to the west of the city, to which the water is sent by four canals. Besides, the water must be shared also to the fields in the upper part of the fan from the upper stream. The privilege has been endowed to the farmers who cultivate those paddy fields as a customary water right since the feudal age (Fig. 1).

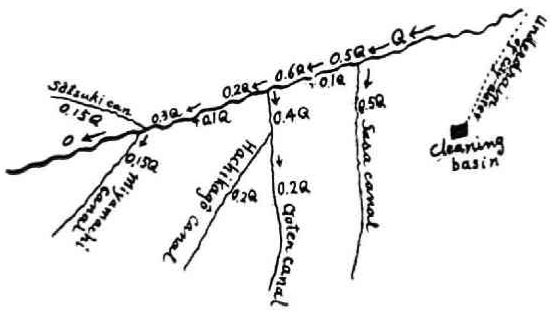

Fig. 1 A brief map of the route of irrigation canals drawing water from the Mamigasaki river.

Thereupon, the Municipal Water Supply Bureau was interested in the use of deep seated groundwater under the fan as a new source of water by means of several deep wells. In the period of 1948 to 1956, fifteen wells 40–120 m in depth have been bored in the fan near its margin. As a result of sucking of the groundwater by these wells, the water-table of the fan descended and many of the private shallow wells and springs on the fan were dried up. Thus, the dependence of citizens upon city water increased more and more. As the reason of this descent of the water-table in the fan, the writer pointed out that it was because the deep wells were sucking up more groundwater from the shallow water seams by pumpage than from the deeper ones, because the strainers were opened to the tube at every water seam regardless of the depth. Hence the strainers were closed above the depth of 80 feet to prevent the descent of water-table in the fan. But the effect of this measure was not very clear. It seems that shallow water permeates into deeper layers because the impermeable layers are not thick enough.

Under this condition of water service, the water demand expanded in accordance with the increase of factories in this city encouraged by the industrialization policy since 1950.

The descent of the water-table in the fan seems to be a general tendency since the Meiji Era (1868–1911). It is not meerly because of the sucking of water by the deep wells in recent times. This tendency has been caused, on the one hand, by the frequent floods owing to heavy rains accelerated by the deforestation in the headwater region of the Mamigasaki river. By these floods, the river bed was eroded near the apex of the fan, so the amount of permeation of the river water into the fan gradually decreased, on the other hand, the permeation of river water into the fan was also arrested by the construction of embankments along the river banks to defend the inundations. For example, after the flood of May 7–9, 1920, due to a heavy rain, 284 out of 1,248 shallow wells in the city were dried up from June to October, and the water-table of remaining wells generally descended by 30 cm to 100 cm during this period (Fig. 3).

According to these conditions of groundwater in the fan, the city authority already carried out the construction of an aqueduct for city-water service in 1917 to 1921 feeding on flowing water of the Mamigasaki river together with the underflow or infiltrated water in its flood plain near the apex of the fan. This water is conducted through an underdrain 6 feet high and 4 feet wide to a cleaning basin for the distance of 900 m, and is distributed to the urban area covering the lower part of the fan feeding the population of 49,758 with the water volume of 12,000 m^3/d. This water source, now enumerated as No. 1 source, and after that in 1944, 1949 and and 1951 respectively, new sources were provided as supplementary to No. 1 source

Photo. 2 Shallow draw-well by rope, in the western Part of Yamagata City. Fruit trees on both sides of the well are "Kaki" (Persimmon) (By courtesy of Assoc. Prof. T. Kato of Yamagata Univ.).

Table I Increase of water source in Yamagata City in respective year.

Source number	Provided year	Water volume (at the outset)	Water volume (in the respective year)	Feeding population (in the respective year)
No. I	1921	12,000 m^3/d	m^3/d	49,758
No. II	1944	1,850	13,850	79,206
No. III	1949	5,300	19,150	90,984
No. IV	1951	1,450	20,500	105,341

by deep wells in the fan, as is shown in Table I.

The daily supply of city-water volume per capita in 1951 was only 200 litres, so, new resource of city-water and industrial water was indispensable besides irrigation water.

III The water resources in the environs of Yamagata City

The general features of the resources in the environs of Yamagata City are as follows.

1) Water of the Mamigasaki river and also groundwater of the Mamigasaki fan seems to be close to the limit of exploitation using present equipments.

2) Groundwater of the Yamagata Basin seemed to contain some amount of natural gas according to the survey by the Geological Survey of Tokyo in 1951, with great many samplings throughout the entire basin. Among them, the samples of groundwater in the northern half of the basin indicated that there a considerable amount of natural gas was dissolved, and there the gas is utilized for domestic

fuel by the farmers. So that, much of the groundwater in the basin is unsuitable for city-water or irrigation water due to its rusty odour or its impurity. Exceptions are several artesian wells at Iizuka and Funamachi in the central part of the basin.

3) Water of the Su river, the main river running through the center of the basin is strongly acidic (pH 3–4) owing to its tributary at the southern margin of the basin fed by hotsprings and sulphur smelters on the slope of Zao volcano. Because of the quality of water, the water of this river is unsuitable for city-water and also for irrigation.

IV Schemes for the development of new water resources

By the member of the Inquiring Committee of the city set up in 1956 several schemes for the water resources have been proposed. Those are as follows:

1) Construction of a concrete dam for the Fudosawa reservoir at the upper stream of the Mamigasaki river with the capacity of 45,000 m^3. An average daily capacity of 9,500 m^3 will be added. The cost of construction of the dam, was estimated about 100 million yen, but it was too expensive for the financial condition of the city at that time. Hence its construction was postponed for several years.

2) A scheme of water supply by a long waterway from the Mogami the largest river in the prefecture, 20 km to the west of the city. But the execution of this plan was suspended because its construction cost was so expensive that it was estimated about 3,000 million yen.

3) A "reverse well" at the upper part of the fan intended the artificial recharge of groundwater in the fan by pouring the surface water into the wells during ample water season; the wells having 4 m in the upper diameter and 2 m in the lower. The walls of the wells were composed of loosely heaped boulders to let the water leak into underground. This idea was carried out at several sites in 1960 and 1961 with some effects.

V Underground geology of the Mamigasaki fan and neighbouring part of the Yamagata Basin

The insufficiency of water resources in Yamagata City has been felt acutely. At this occasion, the writer was requested to make a research for a new water resource by Mayor S. Suzuki in 1955. Hence the writer examined the subterranean geology of the basin and the fan by sixteen geological sections of boring wells in both areas, and he inferred their forming processes geophysically and geomorphologically. The basin has been assumed as a fault-angle depression along the fault fringing the western margin of the Owu Mountains. If so, the Mamigasaki fan, and also the Tachiya fan and the Midare fan to the north, must have

been formed at first under the scarp of fault at the mouths of respective transverse valleys. However, the fans developed eastward over the estimated fault line, to the upstream valley. Among them the Mamigasaki fan is steeper in its surface slope than the other two owing to its excessive amount of river gravels derived from the landslides or rock avalanches from the valley sides of the source region of this river on the northern slopes of Zao volcanic group. The fan covers an area of 24 sq. km. and has a diameter of 6 km from its apex (235 m ab. s.l.) to its margin (120 m ab. s. l.). The projection of the fault scarp in the fan is assumed to coincide with the contour of 150 m (Fig. 2).

The fundamental character of underground geology of the basin and the fan ought to be recognized in the faulting and the configuration of foundation rocks. Hence, the authorities of Yamagata City and their cooperators made efforts to find the accurate position of the fault line underlying the fan by seismic method in 1957. It was found as the result of it that the projection of the fault line is passing through the central part of the urban quarter of the city, roughly along the contour line of 150 m, 2 km from the margin and one thirds of the diameter of the fan. The configuration of the foundation rocks of the fan has been examined by the electric method and its result has shown a very deep V-shaped valley before fanglomerates accumulated in the Mamigasaki valley, as is shown in Fig. 2. At the valley mouth crossing the fault line, the foundation rocks are assumably lying 200 m or more in depth, according to the observation at a deep well at the Momiji Park in the eastern part of the urban quarter, and the fanglomerates at this well composed mainly of andesitic gravels in the upper part from horizon of 167 m depth, and in the lower part from this horizon predominantly of liparitic and granitic gravels. The former gravels are likely derived from Zao volcanic group and the latter from the foundation rocks of the upper valleys of this river.

The depth of the foundation rocks of the Yamagata Basin was assumed to be 300 m or more by a deep test boring at a site in the central part of the basin, 100 m above the sea level to the north-west of Yamagata City. It seems rather unexpectedly deep so that the geophysical methods were not applicable with exactness. It was recognized that the foundation rocks were of Pliocene. And it may be shown that the throw of the fault scarp in the fault-angle depression is in a great measure and it may coincide with the depth of the buried valley mouth of the Mamigasaki river.

The fanglomerates of the Mamigasaki fan are classified into seven horizons by K. Fujiwara who correlated them by the columnar profiles of boring wells. According to him, I-horizon is a superficial fanglomerate that consists of gravel beds, 15–25 m thick. It is assumed that II-horizon is lacustrine deposits consisted

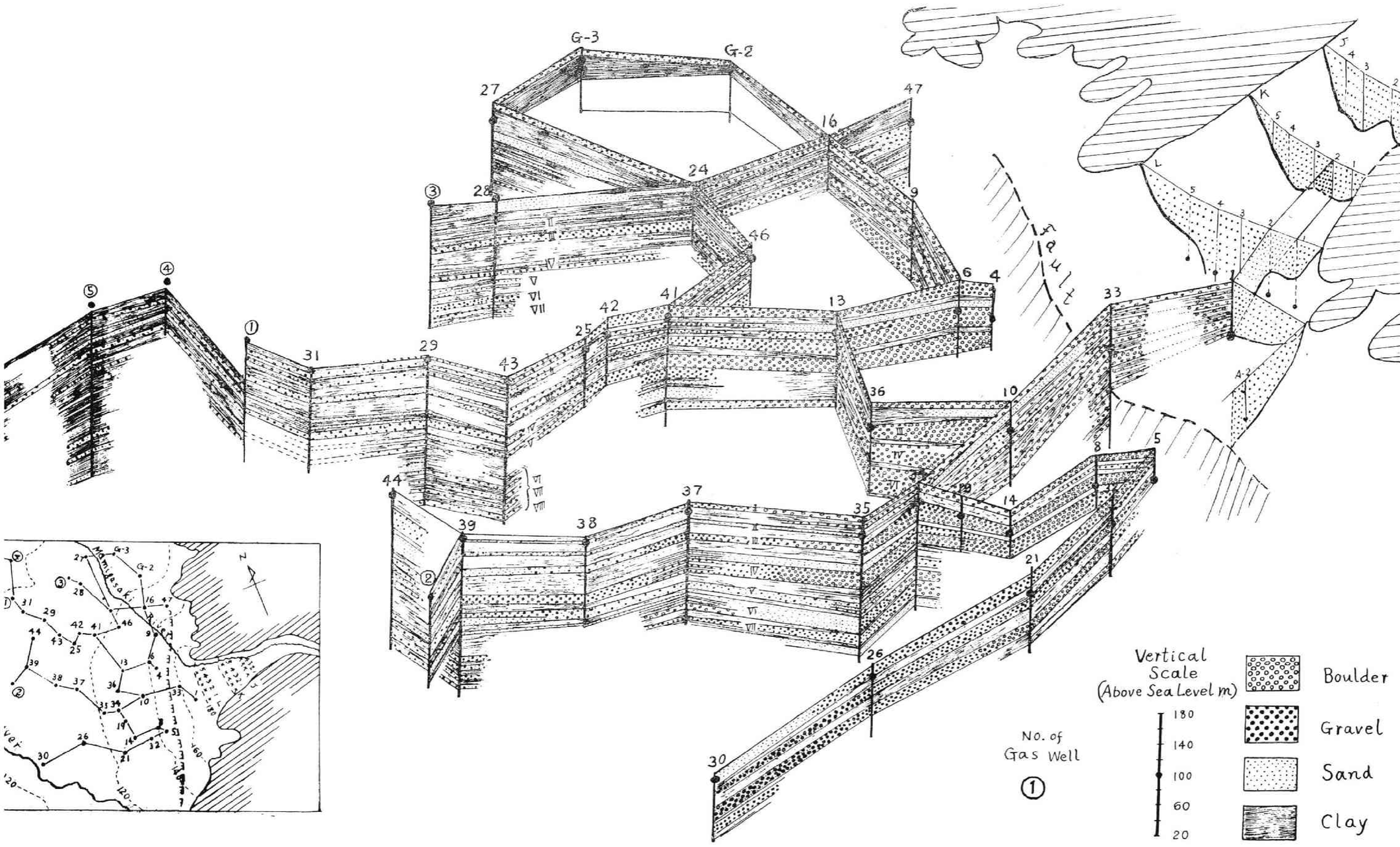

Fig. 2 Underground structure of the Mamigasaki fan.

clayey deposits intercalated with lignite and peat beds making an impervious stratum to artesian groundwater. This horizon of the lacustrine deposits may continue to that of the basin. But in the fan, these deposits of this horizon are distributed as lense-like seams in the western part of the fan. III- and IV-horizons are composed of gravels and boulders, and those are the principal water bearing horizons. The thickness of both horizons is 15–30 m intervening clay bed. These water bearing horizons are correlated to the natural-gas bearing horizons at the northern margin of the basin deposits which have been recognized as lacustrine. V-horizon is composed of thin sand beds at the lower margin of the fan and is 5 m thick. This horizon in the central part of the fan turns to a lens-like seam. So the horizon is assumed as a deltaic deposit of the Mamigasaki river pouring into the "Palaeo-Yamagata Lake". This horizon is developed farther among the basin deposits as clayey lacustrine deposit. VI- and VII-horizons are composed of gravels and boulders, as lower important water-bearing layers, distributed in the fan at the depth lower than 110 m, and it can be traced into the central part of the basin below the depth of 150 m (120–200 m).

VI The two-fold structure of the fanglomerates in the Mamigasaki fan

As stated in the preliminary report in this Science Reports in 1959, the writer has proposed the two-fold structure of the Mamigasaki fan, when he was in search of a new water resource to solve the severe defficiency of the water-supply in Yamagata City. The two-fold structure is composed of the primary and secondary fans. The latter may also be called a "superficial fan" as it is seen as the surface topography of the Mamigasaki fan. The primary fan may also be called a "buried fan" underlying the deposits of the Yamagata Basin, formed under the fault scarp by the primary Mamigasaki river in the primary process of the fault-angle depression during Pleistocene epoch. The primary fan seems to extend westward to the central part of the present basin and its fanglomerates interfinger with the lacustrine deposits at its margin, and its apex merges gradually toward the east into the Mamigasaki valley accompanying with the bottom erosion of the river. The two-fold underground structure of the fan has been inferred by geophysical observations above stated and the geological data obtained by means of many boring wells. Hence, the writer has been inclined to expect that this primary fanglomerates under the Yamagata Basin must have a capacity of 40 million tons of rechargeable clear water annually because it is circulating through the porous layers of fanglomerates fed by surrounding water sources in the basin. The water volume sucked out of the buried primary fan is larger than the amount from the secondary Mamigasaki fan as is shown in Table II.

The bottom of the reservoir may be more than 300 m in depth, but the deep seated groundwater will be unsuitable for the waterworks because of its quality under the stagnant condition preventing circulation, besides the cost of taking water from the deeper water seams will be prohibitive.

VII The present status of the water-works in Yamagata City

The opinion concerning the characteristic feature of groundwater condition of the Mamigasaki fan may be applicable to the neighbouring fans of Tachiya and Midare. In the former fan, many boring wells are providing the water for industrial use, and the existence of the water has already been verified by the city authorities. Thus the difficult problem of the water supply in Yamagata City was solved by the available water with estimated capacity of 40 million tons in the primary fan and 15 million tons of groundwater in the secondary fan together with flowing water of the Mamigasaki river. The annually available water volume for the waterworks of

Table II The water volume in the waterworks of Yamagata City.
(April 1962–March 1963)

I City-water.

No.	Source	Daily volume average(m^3)	per capita maximum (litre)	Daily average volume (m^3)	Volume per annum (m^3)
I	Urban area (Mamigasaki river)	261	361	25,003	9,126,095
II	Chitose (Groundwater)	126	200	294	107,310
III	The North (〃)	60	90	304	110,960
IV	The West (〃) (I)	99	169	383	139,795
V	The West (〃) (II)	68	196	133	48,545
Total				26,117	9,532,705

II Groundwater for city-water by deep wells.

Well number	Depth of well (m)	Diameter of well tube (cm)	Daily water volume (m^3)	Water volume per annum (m^3)
1	106.0	30	1,270	463,550
3	203.0	30	3,500	1,277,500
10	121.0	30	2,400	876,000
16	60.8	30	1,440	525,600
37	109.0	20	168	61,320
47 (artesian)	147.3	10	900	33,850
Total				3,237,820

III Groundwater for irrigation water by deep wells.

Well number	Depth of well (m)	Diameter of well tube (cm)	Daily volume (m^3)	Supplying days	Volume per annum (m^3)
6	39.5	20	720	17.9	132,804
9	75.8	30	4,140	40.5	165,870
14	100.0	30	4,500	33.8	152,100
15	91.0	30	3,600	51.2	184,320
19	109.0	30	4,061	62.4	253,406
20	91.0	30	4,500	63.5	285,750
21	85.0	30	4,500	64.6	290,700
22	69.7	30	5,400	66.0	356,400
25	150.0	?	6,710	45.7	296,647
26	119.6	35	6,300	42.3	266,496
28	76.0	30	3,960	67.8	268,488
29	145.0	35	8,118	64.1	520,363
30 (artesian)	75.8	30	3,600 (artesian water 1,080)	58.8	211,680
31 (〃)	91.0	35	5,760 (〃 800)	46.1	255,536
32	180.0	?	5,603	34.0	190,502
34 (〃)	75.8	?	3,600 (artesian water 900)	50.3	151,080
35 (〃)	150.6	30-20	4,939 (〃 2,963)	30.4	150,146
36 (〃)	151.5	35	7,274 (〃 1,723)	56.1	418,071
38 (〃)	80.0	25	1,800 (〃 540)	62.5	112,500
41 (〃)	182.0	30-20	720 (〃 720)	31.0	104,408
42 (〃)	200.0	30-20	4,860 (〃 1,270)	85.7	416,502
44 (〃)	200.0	30-20	6,300 (〃 2,000)	17.4	109,620
45 (〃)	182.0	30-20	3,600 (〃 450)	28.8	101,880
46 (〃)	186.5	30-20	5,040 (〃 1,450)	44.6	224,784
48	182.0	35-25	9,500	40.8	387,600
49 (〃)	200.0	30-20	5,369 (〃 469)	37.1	199,190
50	136.0	35-25	3,970	27.0	107,190
Total					6 359,623

IV Grounwater for industrial use by deep wells (include some department-stores).

Well number	Depth of well (m)	Diameter of well tube (cm)	Daily water volume (m^3)	Water volume per annum (m^3)
4 (Department-store)	45.5	25	600	216,000
5 (〃)	101.4	35	715	257,400
8 (〃)	100.0	30	750	270,000
11 (Newspaper office)	91.0	35	108	38,880
12	105.0	25	200	72,000
13	28.0	15	180	64,800
17	71.0	20	400	144,000
18 (Hospital)	75.8	20	1,000	360,000
23	45.5	30	1,200	432,000
24	210.0	35-30	4,300	1,548,000
27	30.8	?	15	5,400
33	59.0	?	500	180,000
43	85.0	25	480	172,800
Total				3,766,100

V Whole volume of groundwater utilized in the water-works in Yamagata City in this year.

1) City-water	3,237,820 m³
2) Industry, etc.	3,766,100
3) Irrigation water	6,359,623
4) Artesian water (minus irrigation water)	5,884,655
Total	19,248,198

Yamagata City in recent years is roughly 20 million tons as is shown at the end of Table II-V (Fig. 3).

Groundwater in the shallow water seams of the superficial fan is not desirable, not only because of the descent of water-table but also because the water in the shallow horizon is apt to be unsanitary due to the permeation of sewage. So that almost all of the shallow wells in the urbanized area of the city have been closed. Irrigation water of canals feeds on the water of the Mamigasaki river in the course of the urbanized area, is also soluted recently owing to the inflow of sewage, and became unsuitable for irrigation. For instance, in the Su river the foam of chemical cleaners is afloat so far to the west. So the demand for deep seated groundwater under the basin plain is increasing more and more not only for city-water also for irrigation water in spite of its lower water temperature. However, the capacity of groundwater in the primary fan will be sufficient for these purposes.

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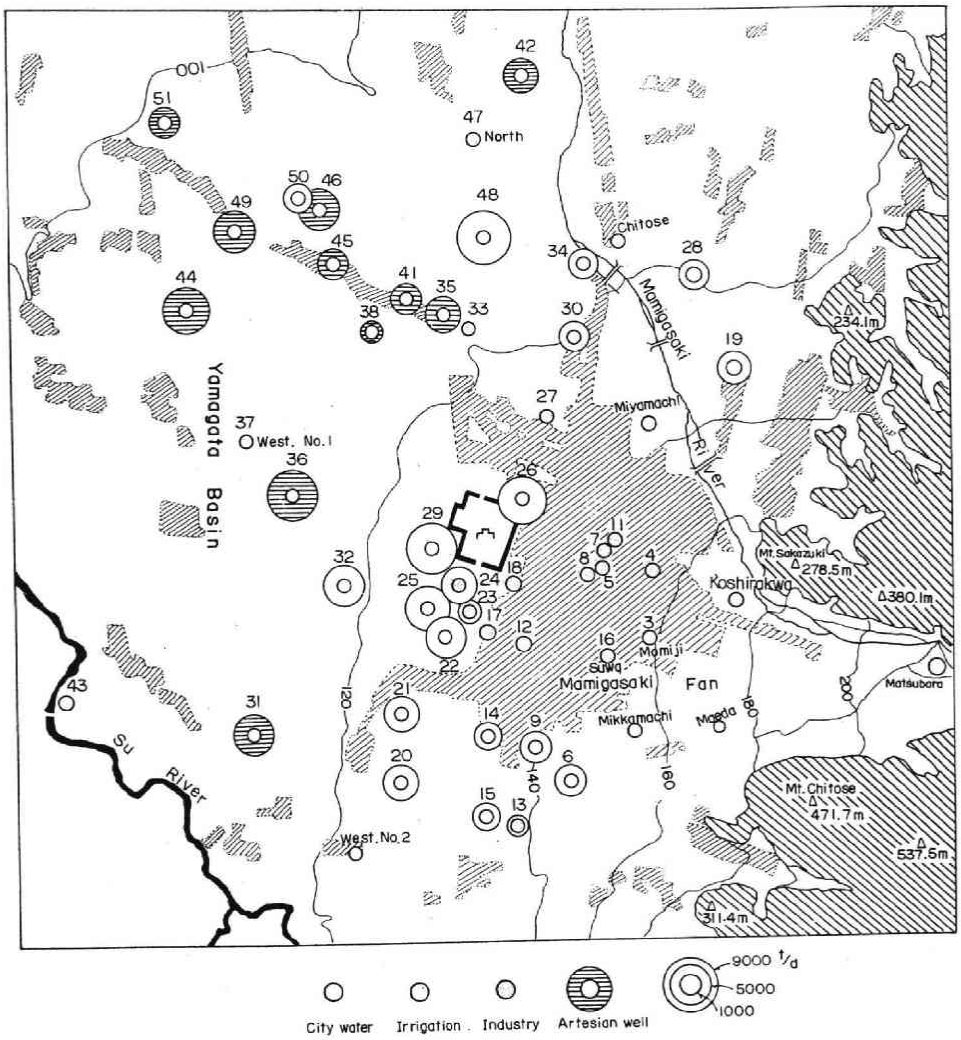

Fig. 3 Distribution of deep wells in the Mamigasaki fan and the neighbonring part of it in the Yamagata Basin